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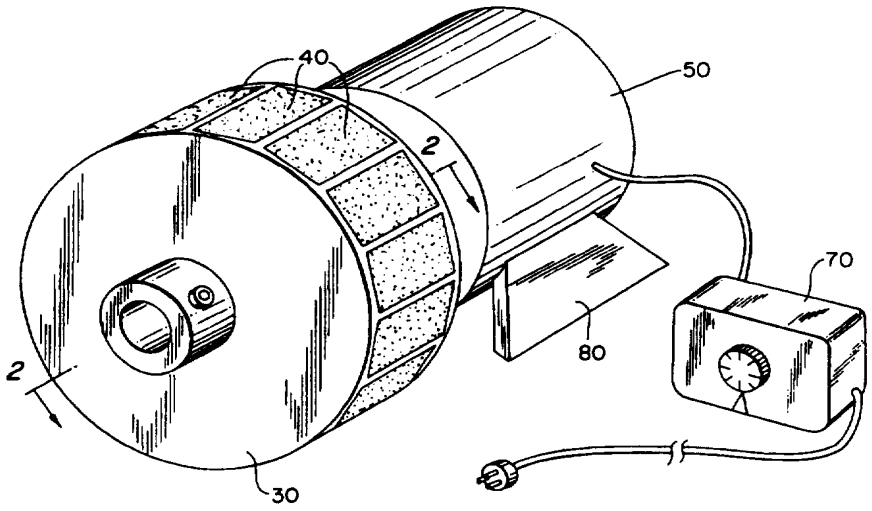

(57) Abstract

Apparatus and methods for treating biological material that utilize moving magnetic fields to induce electric currents in the material. One aspect of the invention uses at least one permanent magnet or a plurality of electromagnets for generating a magnetic field that can pass through the material, and a drive mechanism for moving the magnet relative to the material to induce a direct electric field within the material by means of the movement of the magnetic field. Another aspect of the invention uses a sequential array of electromagnets, each capable of generating a magnetic field that can pass through the material, and a magnet control device for sequentially applying a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the sequential activation of the electromagnets in the array, generate a moving magnetic field along the array thereby inducing a direct electric field within the material. The apparatus and methods can also be used to transport medicant to humans and animals through a transdermal site.

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Description

Apparatus For Inducing DC Electric Fields In Biological Material And Method Of Using It

Technical Field

The present invention relates to apparatus and methods for generating direct current (DC) electric fields in biological material. More specifically, the invention relates to apparatus and methods that create moving magnetic fields and generate DC electric fields in biological material for medical treatment or for inducing the transportation of medicants.

Background Art

DC currents are recognized as providing medicinal benefits when applied to biological materials. For example, DC currents applied on or beneath the skin's surface have been effective in promoting the rapid healing of bones and tissues, and even the regrowth of severed spinal cord axons. The most significant beneficial results are obtained through the application of DC currents that mimic the body's own mechanism.

Typical apparatus have relied on electrode imposed electric fields to impart the electromotive force required to produce the DC electric currents in treated tissues. The electrodes are inserted into the material being treated, e.g., beneath the skin. For example, the use of electrodes to induce electrical currents to treat spinal cord injuries is disclosed in Borgens et al., "Applied Electric Fields in Clinical Cases of Complete Paraplegia in Dogs." Restorative Neurology and Neuroscience, Vol. 5, pp. 305-322 (1993).

The invasive nature of electrodes threatens the beneficial outcome of the clinical treatment and production of uniform DC or rectified AC electric current within the material being treated. For example, the electrodes can

cause infection or become displaced. In addition, the fields produced are non-uniform in both intensity and geometry. Moreover, such electrodes polarize and surround the electrode with oppositely charged ions weakening the field and rendering it non-uniform.

Disclosure of the Invention

Accordingly, the present invention is directed to apparatus and methods for inducing DC electric fields in living cells that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

In particular, the present invention provides a device that allows the production of a DC electric field within biological material, such as living cells and tissue, to obtain a desired clinical benefit without the use of invasive electrodes. This allows for the generation of electric current which mimics the natural mechanism of the cell or tissue. In addition, the present invention avoids the side effects associated with electrodes, such as infection.

The novel concept of generation of the beneficial and curative non reversing electric fields by means of moving magnetic fields allows the treatment of patients without resort to the dangerous invasive techniques required by direct application of equivalent electric fields.

Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by the device particularly pointed out in the written description and claims hereof as well as the appended drawings.

To achieve these and other advantages and in accordance with the purpose of the invention, as embodied and broadly described, the invention provides an apparatus of either permanent or electromagnets arranged and prepared so as to cause the spatial movement of the arranged or generated magnetic fields relative to the material in which the desired

DC electric field is to be induced. The movement of such fields by the apparatus induces a Lorentz force on electrons within living cells and tissue exposed to this force and generates a direct current in the cells or tissue.

In a preferred embodiment the invention may include an apparatus for treatment where the magnets are permanent magnetic material with coercivity greater than 1 kOe.

In a preferred embodiment the invention may include an apparatus for treatment where the magnets are a plurality of electromagnets.

In a preferred embodiment the invention may include an apparatus for treatment including at least one driven disk-like member with an outer peripheral surface where magnetic material on the surface is made up of discrete permanent magnets.

In another preferred embodiment the invention may include an apparatus for treatment including at least one driven disk-like member with a groove on its outer peripheral surface, where the magnetic material of discrete permanent magnets is on the surface of the groove.

In another embodiment, the invention may include an apparatus for treatment including at least one driven disk-like member with an outer peripheral surface where magnetic material on the surface is made up of a plurality of electromagnets.

In another preferred embodiment the invention may include an apparatus for treatment including at least one driven disk-like member with a groove on its outer peripheral surface, where the magnetic material on the surface of the groove is made up of a plurality of electromagnets.

In another embodiment, the invention includes a sequential array of electromagnets in proximity to the biological material to be treated, a magnet control device disposed to sequentially apply a pulse of electrical current to each electromagnetic in the array in order to generate a moving magnetic field along the array so as to induce a

direct electric field within the treated material by the movement of magnetic fields from the electromagnetic.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description serve to explain the principles of the invention.

Brief Description of the Drawings

FIG. 1 is a schematic perspective view of an embodiment of the invention where the moving magnetic field is generated by a plurality of permanent magnets forming a portion of the outer peripheral surface of a rotating disk-like member.

FIG. 2 is a cross-sectional view of the disk-like member of **FIG. 1** taken along line II-II.

FIG. 3 is a perspective view of another embodiment of the invention where the moving magnetic field is generated by a continuous permanent magnet forming the outer peripheral surface of a rotating disk-like member.

FIG. 4 is a cross-sectional view of the disk of **FIG.** 3 taken along line IV-IV.

FIG. 5 is a perspective view of another embodiment of the present invention where the member creating the moving magnetic field comprises a rotating disk having a V-shaped outer peripheral surface with a plurality of permanent magnets affixed within the V.

FIG. 6 is a cross-sectional view of the disk of **FIG. 5** taken along line VI-VI.

FIG. 7 is a perspective view of another embodiment of the invention where the device for forming the moving magnetic field comprises a rotating disk-like member having a V-shaped groove in its outer peripheral surface with each of the V-shaped surfaces comprised of a continuous permanent magnet.

FIG. 8 is a cross-sectional view of the disk of **FIG. 7** taken along line VIII-VIII.

FIG. 9 is a perspective view of another embodiment of the present invention having a plurality of rotating disk-like members that induce a moving magnetic field within the arm of a human.

FIG. 10 is a cross-sectional view of the embodiment of **FIG. 9** along line X-X with the flux lines formed by the rotating magnets schematically depicted.

FIG. 11 is a schematic perspective view of another embodiment of the invention where the moving magnetic field is generated by a belt-like member including a continuous magnetic material.

FIG. 12 is a cross-sectional view of a rotating member of **FIG. 11** with the belt thereon.

FIG. 13 is a perspective view of the embodiment of **FIG. 11** where the moving magnetic field is formed by a plurality of permanent magnets affixed to an endless belt.

FIG. 14 is a cross-sectional view of the embodiment of **FIG. 13** taken along line XIV-XIV.

FIG. 15 is a schematic depiction of an embodiment of the invention having an array of electromagnets and a schematic control system used to generate a moving magnetic field by the use of electromagnets.

FIG. 16 is a cross-sectional view of the embodiment of **FIG. 15** taken along line XVI-XVI.

FIG. 17 is a perspective view of an embodiment of the invention where the moving magnetic field is generated by a magnet on a rotating disk.

FIG. 18 is a cross-sectional view of the embodiment of **FIG. 17** taken along line XVIII-XVIII.

FIG. 19 is a schematic view of the embodiment of **FIGS. 17** and **18** depicting the configuration of the magnetic member.

FIG. 20 is a perspective view of a transdermal medicant delivery device using a moving magnetic field to induce the transportation of the medicant.

FIG. 21 is a cross-sectional view of the device of **FIG. 21**.

Best Mode for Carrying Out the Invention

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

The present invention creates a DC electric field in biological material to treat the material. The biological material can be portions of a living human or animal, such as body fluids, cells, tissue, or bone.

The DC electric field can treat the biological material in numerous ways, including promoting regeneration of damaged tissue. For example, the DC electric field can treat trauma (e.g., bruises, torn muscles, and cartilage damage); debilitation; organs by stimulating their regeneration to restore or enhance their functions; damaged or severed human nerves or axons; slow healing bone fractures (nonunions); occlusion of blood flow due to the formation of plaque or other forms of calcification in the blood stream; ailments, such as heart disease and senility, resulting from reduced blood flow to the affected organ; or osteoporosis (both prevention and reversal).

The electric field can also be used to treat the biological material by destroying it or disrupting its normal processes. For example, it can be used to treat cancerous tissues within the human body by means of high electric currents.

The electric field can also be used to increase migration of electrically charged materials through the biological material. For example, the electric field can allow or enhance transdermal transport of efficacious ionic drug components to specific locations within the tissue, thus reducing the amount of drug needed as well as toxic effects from the drug.

The electric field can also be used to decrease human nerve pain by blocking electrical signals along nerve paths.

The present invention creates the DC electric field in the biological material by subjecting it to a moving magnetic field. Ions moving through a magnetic field are acted on by a Lorentz force. This force is usually stated in vector form:

$$\mathbf{F_L} = \mathbf{J} \times \mathbf{B}$$

Where $\mathbf{F_L}$ is the Lorentz force vector, **J** is the current vector (charge ***q*** moving at velocity **V**), and **B** is the magnetic field vector. This equation can be rewritten:

$$\mathbf{F_L} = q\mathbf{V} \times \mathbf{B}$$

Since the charge ***q*** can be either positive or negative, the Lorentz force $\mathbf{F_L}$ will be perpendicular to the plane of the two vectors **V** and **B**, but in or out of that plane depending on the charge. If a magnetic field with a velocity **V** moves relative to a biological material with a cross-sectional area **A**, through which the magnetic field vector **B** is normal, an electromotive force ***E*** is produced in the biological material in the direction perpendicular to both **B** and **V**:

$$E \sim |\mathbf{V}| \cdot |\mathbf{B}| \cdot |\mathbf{A}|$$

The electromotive force will act on any electric charges within the moving magnetic field to create electric currents. In other words, the moving magnetic field creates a DC electric field in the biological material.

The present invention contemplates two different methods of generating the moving magnetic field to form the DC electric field: (1) moving magnet(s) through space; and (2) sequentially activating an array of electromagnets.

Embodiments of the invention using the first method of forming a moving magnetic field are depicted in **FIGS. 1** through **14** and **17** through **21**. In accordance with this aspect of the invention, the present invention includes at least one magnet for creating a magnetic field that can pass through the biological material and a drive mechanism for moving the magnet relative to the material to induce a DC electric field

within the material by means of the movement of the magnetic field.

As embodied herein, the at least one magnet for creating a magnetic field is preferably a permanent, rare earth magnet **40**, having a coercivity of greater than 1 kOe. Preferably the magnet **40** is neodymium-iron-boron ($Ne_2Fe_{14}B$). However, other permanent magnets of lesser strength can be used.

The embodiments of the invention disclosed and explained herein that practice the first method of forming a moving magnetic field use permanent magnets. However, the invention can also be carried out by replacing the permanent magnets with electromagnets. Any conventional electromagnet can be used that has the required strength. Preferably a plurality of electromagnets are utilized. The electromagnets should be connected, by conventional connections, to a power source.

As embodied herein, the drive mechanism for moving the magnet **40**, **40'**, **40''**, or **40'''** relative to the material includes a disk-like member **30**, **30'**, **30''**, or **30'''** or belt-like member **60** or **60'** for holding the magnet, and a device for driving the disk-like member or belt-like member.

Various embodiments of rotating disk-like members **30**, **30'**, **30''**, or **30'''** for holding the magnet are shown in **FIGS. 1** through **14** and **17** through **21**. The disk-like members preferably are made of mild steel or iron. The operation of the apparatus using disk-like members will be explained by reference to the embodiment shown in **FIGS. 1** and **2**.

The disk-like member **30** depicted in **FIGS. 1** and **2** has a plurality of discrete, permanent magnets **40** arranged in a circular array on its rim or outer peripheral surface. The magnets **40** preferably are closely and equidistantly spaced. Preferably each magnet **40** is a rectangular slab. However, different shapes can be used to suit the application of the apparatus.

In this embodiment, the magnets **40** are positioned in rectangular slots **42** machined in the rim of the disk-like member **30**. Each magnet **40** preferably is glued into each slot

42 with a high quality glue. However, other conventional connectors can be used.

To achieve DC current with a slight ripple (fluctuating, but not reversing), the north magnetic poles of all of the magnets 40 are located on the magnets' outer surfaces and the south magnetic poles are located on the opposite inner surfaces that are in contact with the surface of the disk-like member 30. To obtain a true DC equivalent electric field, however, this embodiment would have to be modified to have a single continuous strip with a single outward facing magnetic pole as in the embodiment shown in FIGS. 3 and 4. If the application of the apparatus requires a reversing AC equivalent electric field, the magnets 40 will reverse polarity in such fashion as to generate the desired field pattern.

The device for driving the disk-like member 30 preferably includes a conventional electric motor 50 connected to a variable speed control device 70. The speed control device is adjustable through a wide range of rotary speeds and thereby can adjust the induced current. The rotation of the motor 50 is translated to the disk-like member 30 by means of a shaft 52 held in place by set screw 54. Supports 80 on each side of the motor 50 provide a rigid mount and sufficient clearance for free rotation of disk-like member 30.

The rotation of the disk-like member 30 moves the permanent magnets 40, thus inducing an associated electric field in the biological material by the Lorentz phenomenon. The amplitude of the DC electric current may vary due to variations in flux from the individual magnets on a peripheral surface of the disk. However, a DC electric field is generated, and an electric current generated thereby, as a result of the rotation of the disk-like member 30. The velocity of the magnetic field lines through the biological material for a disk-like member can be determined by the following equation:

$$V = 2\pi r\Omega$$

Where, Ω is the radial velocity and, r is the radius of the disk-like member.

The disk-like member preferably is encased in a casing (not shown) that shields the biological material from the rotating disk-like member **30**. The casing is preferably formed from a non-conducting material, such as glass reinforced plastic or some other non-magnetic structural plastic, preferably having a thickness no greater than one eighth inch (1/8"). The clearance between the casing and the outer surface of magnets preferably is no greater than one eighth inch (1/8").

Another embodiment of the disk-like member **30'** of the present invention is depicted in **FIGS. 3** and **4**, wherein a continuous magnet **40'** forms the major portion of the rim or outer peripheral surface of the disk-like member **30'**. The magnet **40'** is preferably glued in a single slot machined in the rim of the disk-like member **30'**. Preferably, the magnet **40'** is a single continuous strip with a single outward facing magnetic pole. The magnet **40'** preferably has its north and south poles facing outwardly and inwardly, respectively, which produces a true DC current output.

An additional embodiment of the disk-like member **30''** of the present invention is depicted in **FIGS. 5** and **6**. In this embodiment, the rim or outer peripheral surface of the disk-like member **30''** forms a V-shaped groove. As shown in **FIG. 5**, a plurality of pairs of permanent magnets **40''** are arranged in a circular array within slots in the V-shaped groove.

The magnets **40''** preferably are square slabs that are spaced equidistantly along the rim of disk-like member **30''** in closely fitted machined slots shown in **FIG. 6**. Different shapes can be used, however, to suit the application of the apparatus. Each magnet **40''** preferably is glued into each slot with a high quality glue. However, other suitable connectors can be used.

To obtain DC current with a slight ripple, permanent magnets **40''** are mounted on the disk-like member **30''** such that magnets **40''** on opposing sides of the v-shaped groove are directly opposite each other. The magnets **40''** are also arranged so that all magnets **40''** on one side of the V-shaped groove have their north magnetic poles facing outwardly and all magnets **40''** on the other side of the V-shaped groove have their south magnetic poles facing inwardly. Thus, magnets **40''** are attracting in all cases and an endless series of closely spaced transverse magnetic fields are formed in the space between the two inner surfaces. To obtain true DC equivalent electric fields, however, the discrete magnets of this embodiment would have to be modified to be two individual continuous strips, each having a single outward facing magnetic pole, as in the embodiment shown in **FIGS. 7** and **8**. If the application requires a reversing AC equivalent electric field the magnets **8** will reverse polarity is such fashion as to generate the desired field pattern.

The magnetic field between the opposing magnets **40''** forms a semicircular arc above the outer rim of the disk-like member **30''**. The magnetic field's shape and extension above the rim of the disk-like member **30''** is controlled by the angle between the surfaces of the opposing magnets **40''**. The magnets are mounted at an angle ϕ relative to one another. That is, an angle ϕ is formed between the planes formed by the outer surfaces of the magnets **40''**. The angle ϕ varies between zero degrees and one hundred and eighty degrees ($0° \leq \phi \leq 180°$), depending on the application of the apparatus.

Another embodiment of the disk-like member **30'''** is shown in **FIGS. 7** and **8**. In this embodiment, the disk-like member **30'''** has a V-shaped groove similar to the embodiment shown in **FIGS. 5** and **6**. However, the magnets **40'''** in this embodiment are two continuous layers on each of the surfaces of the V-shaped groove. Preferably the magnet **40'''** on one side of the V-shaped groove has its north magnetic pole facing outwardly and the magnet **40'''** on the other side of

the V-shaped groove has its south magnetic pole facing outwardly. Thus, the magnets **40'''** have opposing magnetic poles. This arrangement produces a true DC current output.

The disk-like members can be used in combination to create magnetic fields tailored to the application of the apparatus. For example, **FIGS. 9** and **10** depict a combination of the embodiments shown in **FIGS. 3** and **5**. The combination can be used to treat a human arm.

The disk-like members **30''** are positioned opposite one another. The disk-like members **30'** are also positioned opposite one another. The magnetic pole faces on one side of a plane perpendicular to the two drive axes of the disk-like members **30'** are matched by opposite magnetic pole faces on the other side of that plane. As shown most clearly in the cross-sectional view of **FIG. 10**, the disk-like members **30'** and **30''** produce a focused magnetic field having its greatest strength at a point or region of intersection **45** located equidistant from the magnetic surfaces.

A synchronous system of drive mechanisms (not shown) causes each disk-like member to rotate so that the magnetic fields from the disk-like members move in unison, in parallel, and in the same direction at the region of intersection **45**. This embodiment concentrates the power of the magnetic field at the region of intersection **45**. The concentrated power of the magnetic field allows the apparatus to generate strong electromotive forces within the biological material. This embodiment can be used, for example, to destroy tissue at specific locations.

Though this embodiment develops strong electromotive forces deep within the biological material, it has a relatively weak effect on the external body tissues due to the reduced magnetic field strengths and divergent velocities of the magnetic fields outside the region of intersection **45**. This embodiment and other various similar combinations allow the application of strong electric forces and deep penetration of the body with only slight collateral effect.

A physical barrier (not shown) such as the casing described above is preferably positioned between the arm of the patient being treated and the disk-like members to prevent the arm of the patient from engaging the rotating disk-like members. The speed control and articulated mountings of disk-like members **30** and **30'** also are not shown.

FIGS. 17 and **19** show another embodiment of a system using a single disk-like member. This unitary, portable, rechargeable, magnetic treatment system has a magnetic disk **41** mounted on a side of a disk-like member **31**. The magnetic disk **41** has only a single magnetic pole on the annular outer surface of the disk **41** facing outwardly from the disk-like member **31**. Preferably the north magnetic pole faces outwardly and the south magnetic pole faces inwardly. This arrangement generates a true DC current in the biological material. If an AC current is desired, alternating segments of this surface annular will have opposing magnetic poles. The magnetic disk **41** preferably has a nominal radius of two to nine inches (2" to 9").

The disk-like member **31** is driven by an electric motor **50**. As shown in **FIGS. 18** and **19**, electric motor **50** is mounted on housing **92**. Shaft **93** from motor **50** turns worm gear **94**, which drives gear **95** on disk-like member **31**. The disk-like member **31** spins on bearing shaft **96**.

The motor **50** has a variable speed adjustment that allows for a variety of rotary speeds and resultant induced currents to select proper electric field strength for a specific treatment. Dial **97** adjusts the speed of the disk-like member **31** by varying the voltage from battery **98**. Battery **98** is preferably rechargeable through port **99** or by removal and replacement.

The magnetic disk **41** and disk-like member **31** are encased in a closely fitted housing **92** formed from non conducting material such as glass reinforced plastic or some other structural plastic. The inner surface of the face of the housing **92** that is most proximate and parallel to the outermost face of the magnetic disk **41** is covered by magnetic

shielding **90**, which prevents the passage of the magnetic field. The magnetic shielding **90** has one or more annular openings **91** that allow the magnetic disk's field to exit the housing **92** and penetrate the treated tissue. The number of openings can be altered as treatment may require.

Embodiments of belt-like members **60** and **60'** having permanent magnet(s) affixed thereto are shown in **FIGS. 11** through **14**. The belt-like members preferably are made of fiber-reinforced polymeric material, but any flexible material of sufficient strength would be adequate. The operation of the apparatus using belt-like members will be explained by reference to the embodiment shown in **FIGS. 11** and **12**.

In the system shown in **FIGS. 11** and **12**, the belt-like member **60** has a single, continuous permanent magnetic strip **43** arranged on a flexible belt **65**. The belt-like member **60** runs between disk-like members **66**. The magnet **43** has a single outward facing magnetic pole. Preferably the north magnetic pole faces outwardly away from the belt **65** and the south magnetic pole is in contact with the surface of the belt **65**. The magnet **43** preferably is fixed to the belt **65** with a high quality glue. However, the magnet **43** can be fixed to the belt **65** with any other suitable connector, such as rivets or staples.

The belt-like member is preferably driven by two disk-like members **66** shown in **FIG. 11**. Each disk-like member **66** preferably is slightly wider than belt-like member **60**. Both disk-like members **66** preferably are made of non-magnetic material, such as aluminum or a non ferrous material. The first disk-like member preferably is mounted on shaft **52** from an electric motor **50**, having a variable speed adjustment that allows a wide assortment of rotary speeds. The second disk-like member preferably moves freely between two pillow blocks **68** on a shaft fitted to ball bearings in each pillow block **68**. In **FIG. 11**, supports **80** on each side of the motor **50** and pillow blocks **68** on each side of the second disk-like member **66** provide a rigid mount and sufficient clearance for

free rotation of disk-like members **68** and belt-like member **60**.

The belt and disk-like members of **FIGS. 11** through **14** are preferably encased in a closely fitted, non-conducting material (not shown), such as glass reinforced plastic or some other structural plastic, preferably having a thickness no greater than one eighth inch (1/8"). The clearance between the encasing material and the outer surface of magnets preferably is no greater than one eighth inch (1/8").

In another embodiment of the belt-like member is shown in **FIGS. 13** and **14**. The belt-like member **60'** in this embodiment is a unitary system comprised of closely spaced, discrete, permanent magnets, all with the same polarity. Each magnet **40** is preferably a rectangular slab spaced equidistantly along the length of belt **65**. However, different shapes can be used to suit the specific application of the apparatus. This arrangement produces a DC current with a slight ripple. To obtain true DC equivalent electric fields, the magnets of this embodiment would have to be modified to have the continuous, single magnetic pole shown in **FIGS. 11** and **12**. If the application requires a reversing AC equivalent electric field the magnets **40** will reverse polarity is such fashion as to generate the desired field pattern.

FIGS. 15 and **16** depict an embodiment of the invention that sequentially activates an array of electromagnets to generate a moving magnetic field. In accordance with this aspect of the invention, the present invention includes a sequential array of electromagnets in proximity to the biological material, and a magnet control device disposed to sequentially apply a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the sequential activation of the electromagnets in the array, generate a moving magnetic field along the array thereby inducing a direct electric field within the material.

As embodied herein, the sequential array of electromagnets is formed by closely fitted, equidistantly spaced, C-shaped electromagnets **140**. Each electromagnet **140** in the array can create a magnetic field, which is transverse to the longitudinal axis of the array, in the gap of the electromagnet. More specifically, energized magnetic inductance windings **142**, which are protected by insulation **144**, generate an electromagnetic field in the gap between ferromagnetic plates **146**. Ferromagnetic spacer heads **148** narrow the gap and bring the magnetic field nearer to the biological material.

As embodied herein, the magnet control device includes a control box **170** that sends pulses of electrical current to windings **142** through connecting lines **141**. The control box **170** has control settings **172** for controlling the amount of current sent to the windings **142** of the electromagnets **140** in the array. Thus, the control box **170** can control the magnetic field strength in the array.

This embodiment of the invention achieves spatial translation of the magnetic field by the sequential activation of the electromagnets **140**. In other words, the electromagnets **140** in the array are sequentially activated to move the magnetic field along the array.

The control box **170** first sends current to the windings **142** of the first electromagnet **140** to create a magnetic field. The current to the first electromagnet **140** is then switched off and the second electromagnet **140** is energized within a specific switching time that is shorter than the natural rate at which the magnetic field decays (the e-folding time). This causes the magnetic field lines, which would normally disburse from the first electromagnet **140**, to be drawn along the longitudinal axis of the array to form the magnetic field in the second electromagnet **140**. This process is repeated down the length of the array, thus creating a moving magnetic field that, though perpendicular to the longitudinal axis of the array, translates parallel to that axis along the length of the array. Subsequent magnetic

fields are generated and moved along the array by reactivating the electromagnets **140**, previously deactivated, after the prior magnetic field has moved along the array sufficient distance such that the subsequent magnetic field produced by reactivation of the electromagnets **140** will not significantly affect the prior moving magnetic field further along the array.

The control settings **172** on the control box **170** determine which electromagnets **140** will be activated, and when. Thus, the control box **170** controls the velocity of the magnetic field by timing the activation of the electromagnets **140**. The magnetic field strength and the velocity of the magnetic field, which are both controlled by the control box **170**, determine the intensity of the induced DC electric current in the biological material. Thus, the control box **170** controls the intensity of the DC electric current in the biological material.

The velocity of the magnetic field is limited only by the e-folding time. The e-folding time establishes the maximum Lorentz forces that can be generated in the volume within the array. Growth and e-folding times for the magnetic coil inductances and electrical resistances of the circuit allow switching times and resulting magnetic field velocities that will generate induced electric currents far in excess of the requirements thus far established in research with direct application of electric currents.

Many other geometric configurations are possible, which allows a broad specificity of application. For example, the C-shaped electromagnets **140** could each be slightly rotated about their longitudinal axes. The electromagnets along the longitudinal axis form a helix about the axis. This produces a magnetic field that rotates as it translates along the longitudinal axis. The rotation of the magnetic field causes the field lines to sweep through the biological material in a circular manner and create a secondary, axial Lorentz current. The Lorentz current due to the lateral translation of the magnetic field is radial.

In accordance with another aspect of the invention, the present invention includes an apparatus for transporting at least one medicant to humans and animals through a transdermal site. The apparatus includes a medicant supply located on the site and at least one permanent magnet in proximity to the site. A drive mechanism is disposed to move the magnet relative to the site to induce a direct electric field within the site by means of the movement of the magnetic field from the magnet, the electric field being of sufficient magnitude to increase the rate of transportation of the medicant.

As embodied herein, the medicant supply is a drug saturated pad **71** that can be held in place against the surface of the biological material. As shown in **FIGS. 20** and **21** the transdermal portable, drug induction system includes a plate **72** for holding drug pad **71**. The plate **72** rotates on hinge **73** to allow the placement or removal of the pad.

As embodied herein, the permanent magnet and drive mechanism are essentially the same as those disclosed in **FIGS. 17** through **19**. Dual enclosed magnetic disks **41** are mounted on bearings. The disks **41** are arranged to create a moving magnetic field that traverses the biological material and the drug saturated pad **71**. The moving magnetic field exiting from windows **91** in magnetic shielding **90** and emanating from the opposite magnetic pole surfaces of annular disk magnets **41**, transects drug saturated pad **71**. By means of the generated Lorentz force, the magnetic field causes ionic forms of the drug to penetrate the skin and tissue of the limb or body portion enclosed between drug pad **71** and cushion **74**.

One or both disks are driven by an electrical motor **50** and control circuit with a variable speed adjustment that allows a wide assortment of: rotary speeds; direction of rotation, and times of operation.

In the preferred embodiment, the rotation of the driven magnet **41** connected to gear **95** causes the rotation of facing magnet of opposite polarity freewheeling on shaft **96**.

Housing **92** encloses the unit. The inner surfaces of the housing that are most proximate and parallel to the outermost faces of the magnetic disks are covered by magnetic shielding **90**, which prevents the passage of the magnetic field except through such openings as are provided. The magnetic shielding preferably has two annular openings that allow the magnetic field to exit the housing surfaces and cause transdermal transport of the cations or anions of various drugs through the surface of the skin of the enclosed limb.

In accordance with yet another aspect of the invention, the present invention includes an apparatus for transporting at least one medicant to humans and animals through a transdermal site. The apparatus includes a medicant supply located on the site and a sequential array of electromagnets in proximity to the site. A control device is disposed to sequentially apply a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the sequential activation of the electromagnets in the array, generate a moving magnetic field along the array thereby inducing a direct electric field within the material in proximity to the site, the electric field being of sufficient magnitude to increase the rate of transportation of the medicant. This embodiment of the invention is similar to the embodiment shown in **FIGS. 20** and **21**, except instead of using the system disclosed in **FIGS. 17** through **19**, it uses the system disclosed in **FIGS. 15** and **16**. More specifically, one side of the array of the C-shaped electromagnets **140** shown in **FIG. 15** replaces one of the magnetic disks **41** shown in **FIG. 21**, and the other side of the array of the electromagnets **140** replaces the other of the magnetic disks **41**.

Each of the above embodiments and numerous other possible configurations are based on the concept of a moving magnetic field generating an electric current in or on a biological material without the use of electrodes. Magnetic fields of 2000 gauss, which can be achieved by both permanent and electromagnets, coupled with the velocities generated by

electric motor rotational speeds, allow Lorentz forces that meet or exceed electric currents used by known devices. The systems preferably can generate an electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 100.0 V/Meter. The systems also preferably generate a DC electric current in the biological material in the range of from 0.000001 to 10.0 amperes. Thus, the present invention generates DC currents for medical treatment while eliminating the risk to the patient caused by inserting electrodes.

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

Claims

1. An apparatus for treating biological material, the apparatus comprising:

at least one permanent magnet for generating a magnetic field that can pass through the material; and

a drive mechanism for moving the magnet relative to the material to induce a direct electric field within the material by means of the movement of the magnetic field.

2. The apparatus of claim 1 wherein the apparatus includes a plurality of permanent magnets for generating the magnetic field.

3. The apparatus of claim 2 wherein the magnets include permanent magnetic material having a coercivity greater than 1 kOe.

4. The apparatus of claim 3 wherein the apparatus includes at least one driven disk-like member having an outer peripheral surface, the magnetic material being discrete permanent magnets on the surface.

5. The apparatus of claim 3 wherein the apparatus includes at least one driven disk-like member having an outer peripheral surface that includes a groove therein, the magnetic material being discrete permanent magnets on the surface of the groove.

6. The apparatus of claim 3 wherein the apparatus includes at least one driven belt-like member having an outer surface, the magnetic material being discrete permanent magnets on the surface.

7. The apparatus of claim 1 wherein the apparatus includes at least one driven disk-like member having an outer peripheral surface, the magnetic material being a discrete permanent magnet comprising a major portion of the outer peripheral surface.

8. The apparatus of claim 7 wherein the biological material comprises portions of a living human.

9. The apparatus of claim 8 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

10. The apparatus of claim 7 wherein the biological material comprises portions of a living animal.

11. The apparatus of claim 10 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

12. The apparatus of claim 1 wherein the apparatus generates a DC electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 100.0 V/Meter.

13. The apparatus of claim 1 wherein the apparatus generates a DC electric current in the biological material in the range of from 0.000001 to 10.0 amperes.

14. An apparatus for treating biological material, the apparatus comprising:

a plurality of electromagnets for generating a magnetic field that can pass through the material; and

a drive mechanism for moving the electromagnets relative to the material to induce a direct electric field within the material by means of the movement of the magnetic field.

15. The apparatus of claim 14 wherein the apparatus includes at least one driven disk-like member having an outer peripheral surface, the electromagnets being mounted on the surface.

16. The apparatus of claim 14 wherein the apparatus includes at least one driven disk-like member having an outer peripheral surface that includes a groove therein, the electromagnets being mounted on the surface of the groove.

17. The apparatus of claim 14 wherein the biological material comprises portions of a living human.

18. The apparatus of claim 17 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

19. The apparatus of claim 14 wherein the biological material comprises portions of a living animal.

20. The apparatus of claim 19 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

21. The apparatus of claim 14 wherein the apparatus generates a DC electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 100.0 V/Meter.

22. The apparatus of claim 14 wherein the apparatus generates a DC electric current in the biological material in the range of from 0.000001 to 10.0 amperes.

23. An apparatus for treating biological material, the apparatus comprising:

a sequential array of electromagnets, each capable of generating a magnetic field that can pass through the material; and

a magnet control device for sequentially applying a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the sequential activation of the electromagnets in the array, generate a moving magnetic field along the array thereby inducing a direct electric field within the material.

24. The apparatus of claim 23 wherein the biological material comprises portions of a living human.

25. The apparatus of claim 23 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

26. The apparatus of claim 23 wherein the biological material comprises portions of a living animal.

27. The apparatus of claim 25 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

28. The apparatus of claim 23 wherein the apparatus generates a DC electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 0.1 V/Meter.

29. The apparatus of claim 23 wherein the apparatus generates a DC electric current in the biological material in the range of from 0.000001 to 0.01 amperes.

30. An apparatus for transporting at least one medicant to humans and animals through a transdermal site, the apparatus comprising:

a medicant supply located on the site;

at least one permanent magnet for generating a magnetic field at the site;

a drive mechanism for moving the magnet relative to the site to induce a direct electric field within the site by means of the movement of the magnetic field, the electric field being of sufficient magnitude to increase the rate of transportation of the medicant.

31. The apparatus of claim 30 wherein the apparatus generates a DC electric field at the site having a field strength in the range of from 0.001 volts per meter to 1.0 volts per meter.

32. The apparatus of claim 30 wherein the apparatus generates a DC electric current at the site in the range of from 0.000001 to 0.1 amperes.

33. The apparatus of claim 30 wherein the apparatus includes a drive control for controlling the velocity of movement of the permanent magnets.

34. The apparatus of claim 30 wherein the apparatus includes a drive control for controlling the rate of transportation of the medicant.

35. The apparatus of claim 30 wherein the apparatus includes a housing, the housing further including magnetic shielding, the shielding selectively limiting the application of the magnetic field to the site.

36. An apparatus for transporting at least one medicant to humans and animals through a transdermal site, the apparatus comprising:

a medicant supply located on the site;

a sequential array of electromagnets, each capable of generating a magnetic field at the site;

a control device for sequentially applying a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the

sequential activation of the electromagnets in the array, generate a moving magnetic field along the array thereby inducing a direct electric field within material in proximity to the site, the electric field being of sufficient magnitude to increase the rate of transportation of the medicant.

37. The apparatus of claim 36 wherein the apparatus generates a DC electric field at the site having a field strength in the range of from 0.001 V/Meter to 0.1 V/Meter.

38. The apparatus of claim 36 wherein the apparatus generates a DC electric current at the site in the range of from 0.000001 to 0.01 amperes.

39. The apparatus of claim 36 wherein the control device controls the rate of transportation of the medicant.

40. The apparatus of claim 36 wherein the apparatus includes a housing, the housing further including magnetic shielding, the shielding selectively limiting the application of the magnetic field to the site.

41. A method of treating biological material comprising the steps of:

providing at least one permanent magnet in proximity to the material; and

moving the magnet relative to the material to induce a direct current electric field within the material by the movement of magnetic fields from the magnet.

42. The method of claim 41 wherein the biological material comprises portions of a living human.

43. The method of claim 42 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

44. The method of claim 41 wherein the biological material comprises portions of a living animal.

45. The method of claim 44 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

46. The method of claim 41 including the step of generating an electric field in the biological material

having a field strength in the range of from 0.001 V/Meter to 100.0 V/Meter.

47. The method of claim 41 including the step of generating a DC electric current in the biological material in the range of from 0.000001 to 10.0 amperes.

48. A method of treating biological material comprising the steps of:

providing a plurality of electromagnets in proximity to the material; and

moving the electromagnets relative to the material to induce a direct current electric field within the material by the movement of magnetic fields from the magnets.

49. The method of claim 48 wherein the biological material comprises portions of a living human.

50. The method of claim 49 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

51. The method of claim 48 wherein the biological material comprises portions of a living animal.

52. The method of claim 51 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

53. The method of claim 48 including the step of generating an electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 100.0 V/Meter.

54. The method of claim 48 including the step of generating a DC electric current in the biological material in the range of from 0.000001 to 10.0 amperes.

55. A method of treating biological material comprising the steps of:

providing a sequential array of electromagnets in proximity to the material;

applying a pulse of electrical current to each electromagnet in the array to generate a magnetic field in the electromagnet and, by the sequential activation of the electromagnets in the array, generate a moving magnetic field

along the array to induce a direct electric field within the material.

56. The method of claim 55 wherein the biological material comprises portions of a living human.

57. The method of claim 56 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

58. The method of claim 55 wherein the biological material comprises portions of a living animal.

59. The method of claim 58 wherein the biological material comprises a material selected from the group consisting of: body fluids, cells, tissue and bone.

60. The method of claim 55 including the step of generating an electric field in the biological material having a field strength in the range of from 0.001 V/Meter to 0.1 V/Meter.

61. The method of claim 55 including the step of generating a DC electric current in the biological material in the range of from 0.000001 to 0.01 amperes.

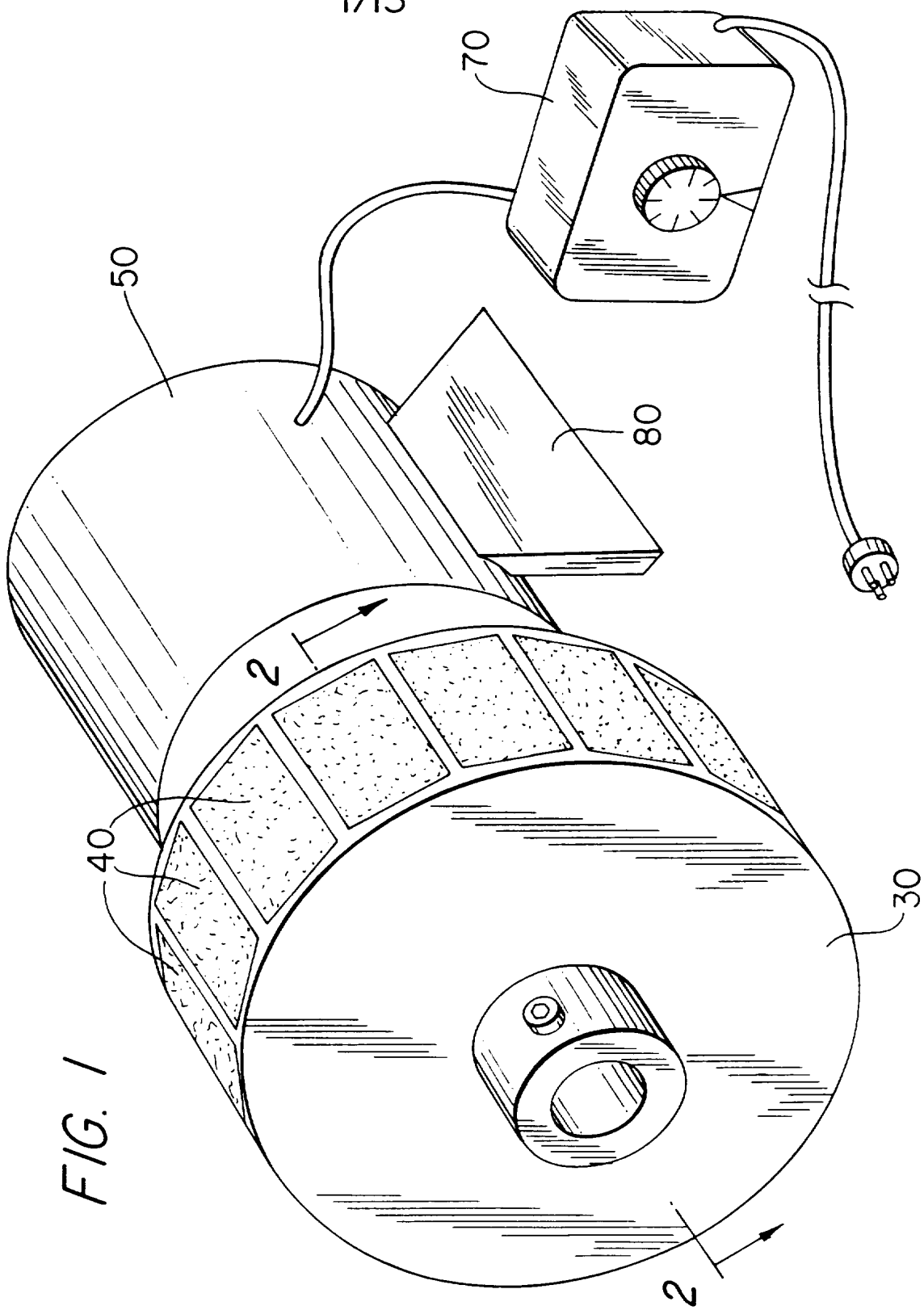

FIG. 1

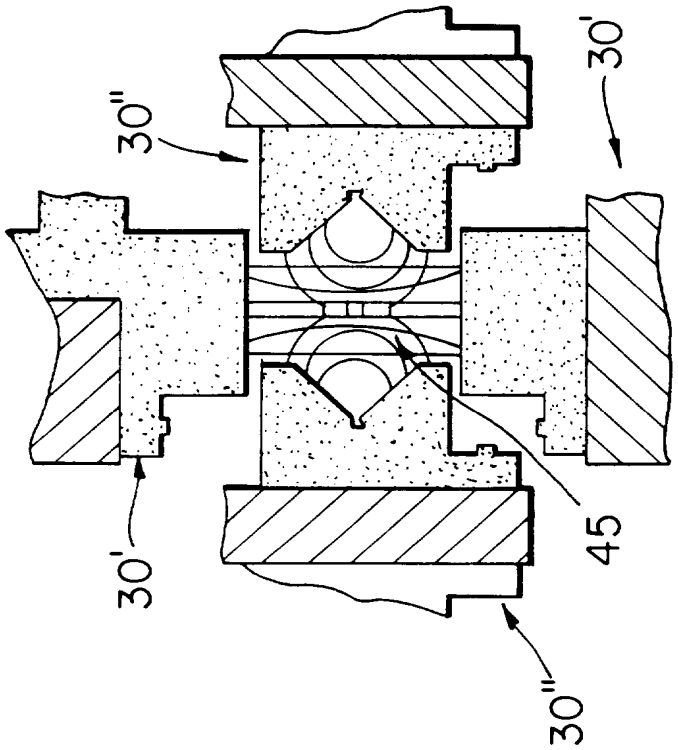

FIG. 10

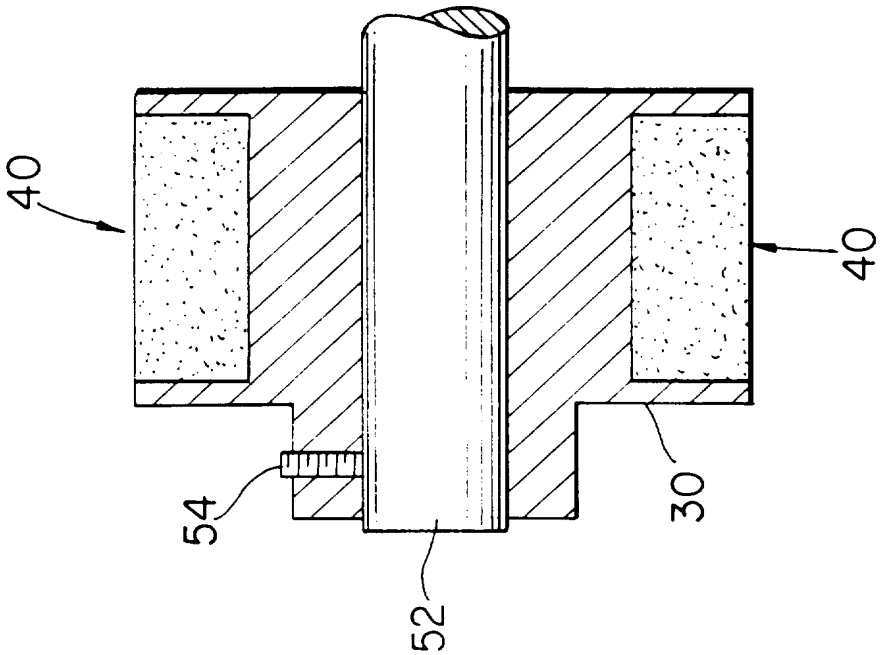

FIG. 2

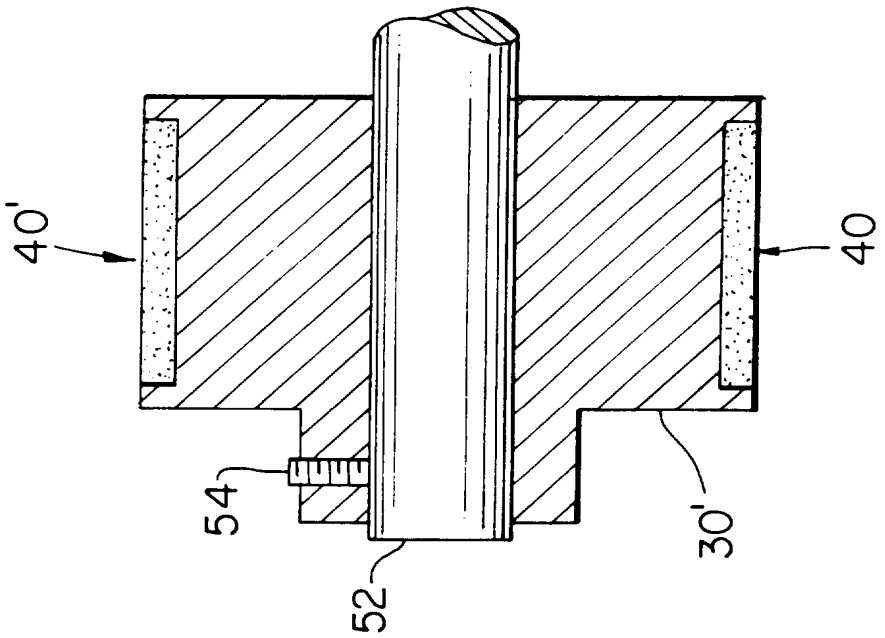

FIG. 4

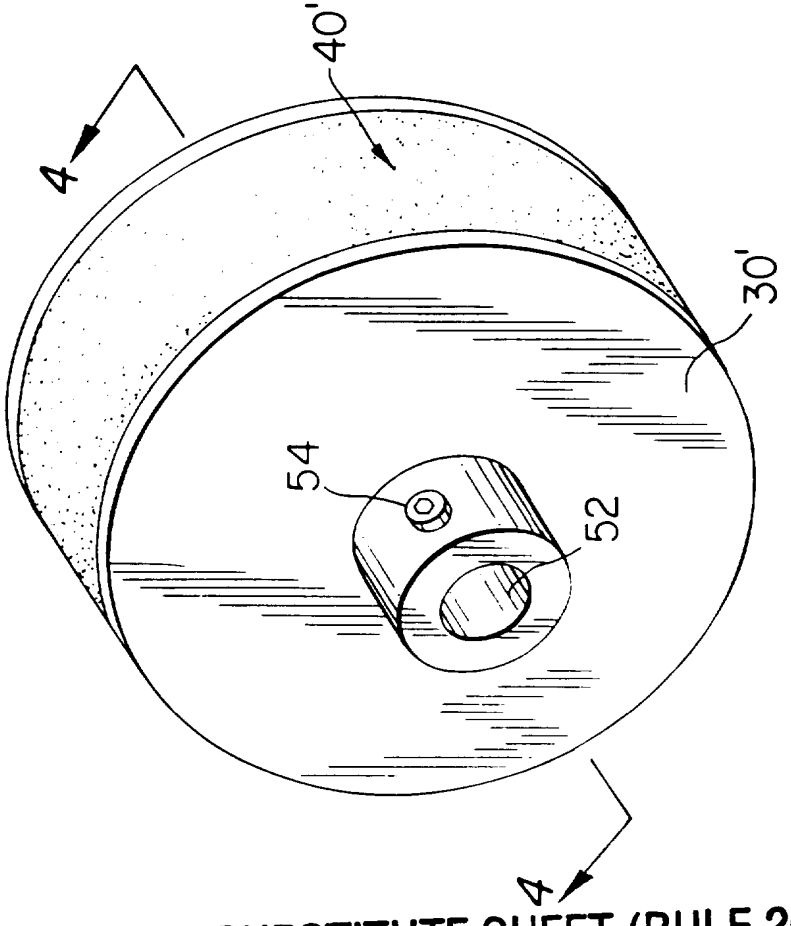

FIG. 3

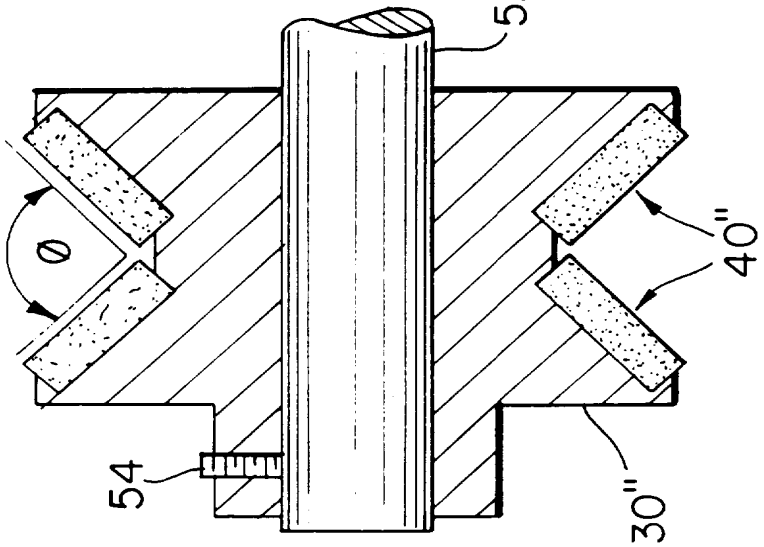

FIG. 6

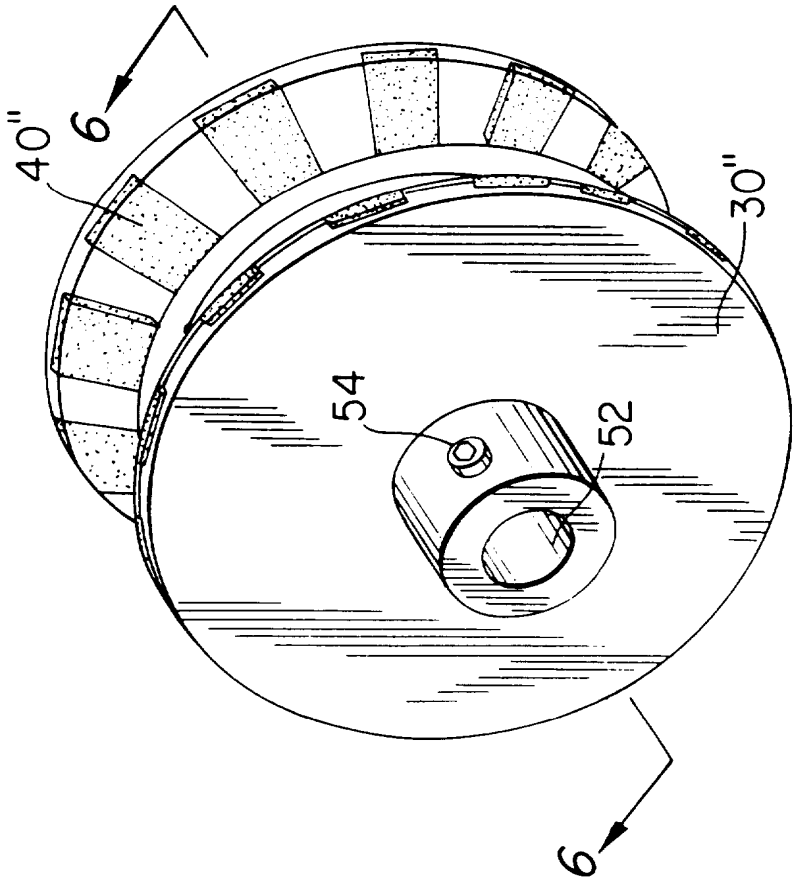

FIG 5

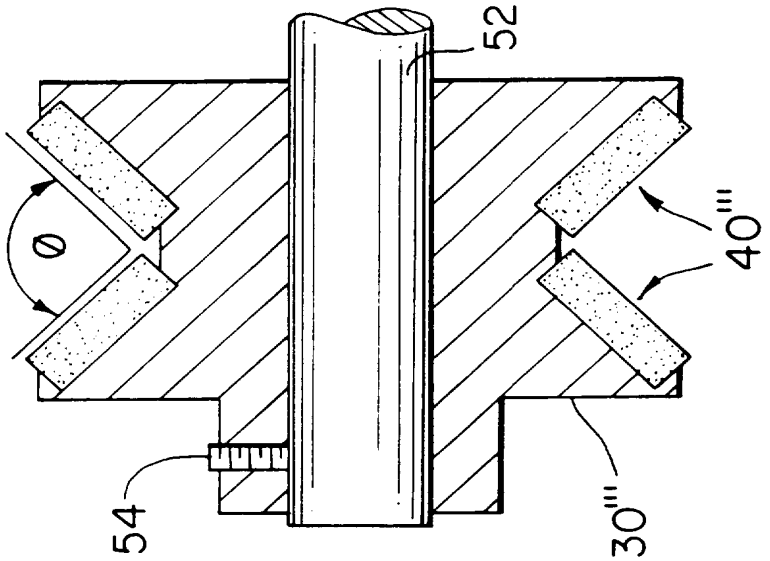

FIG. 8

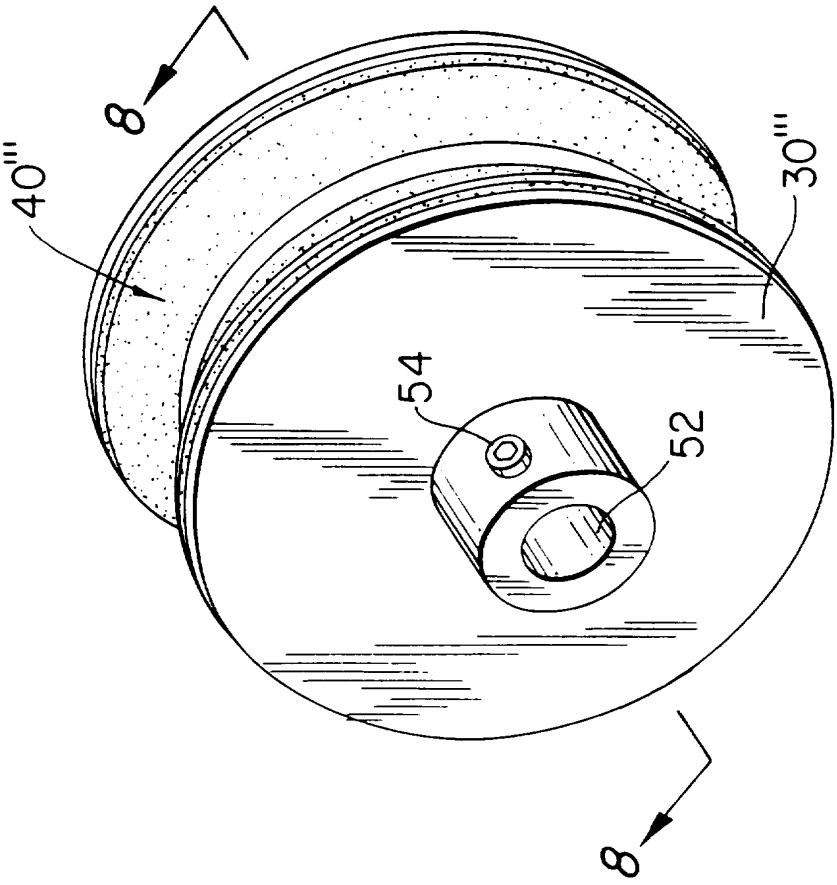

FIG. 7

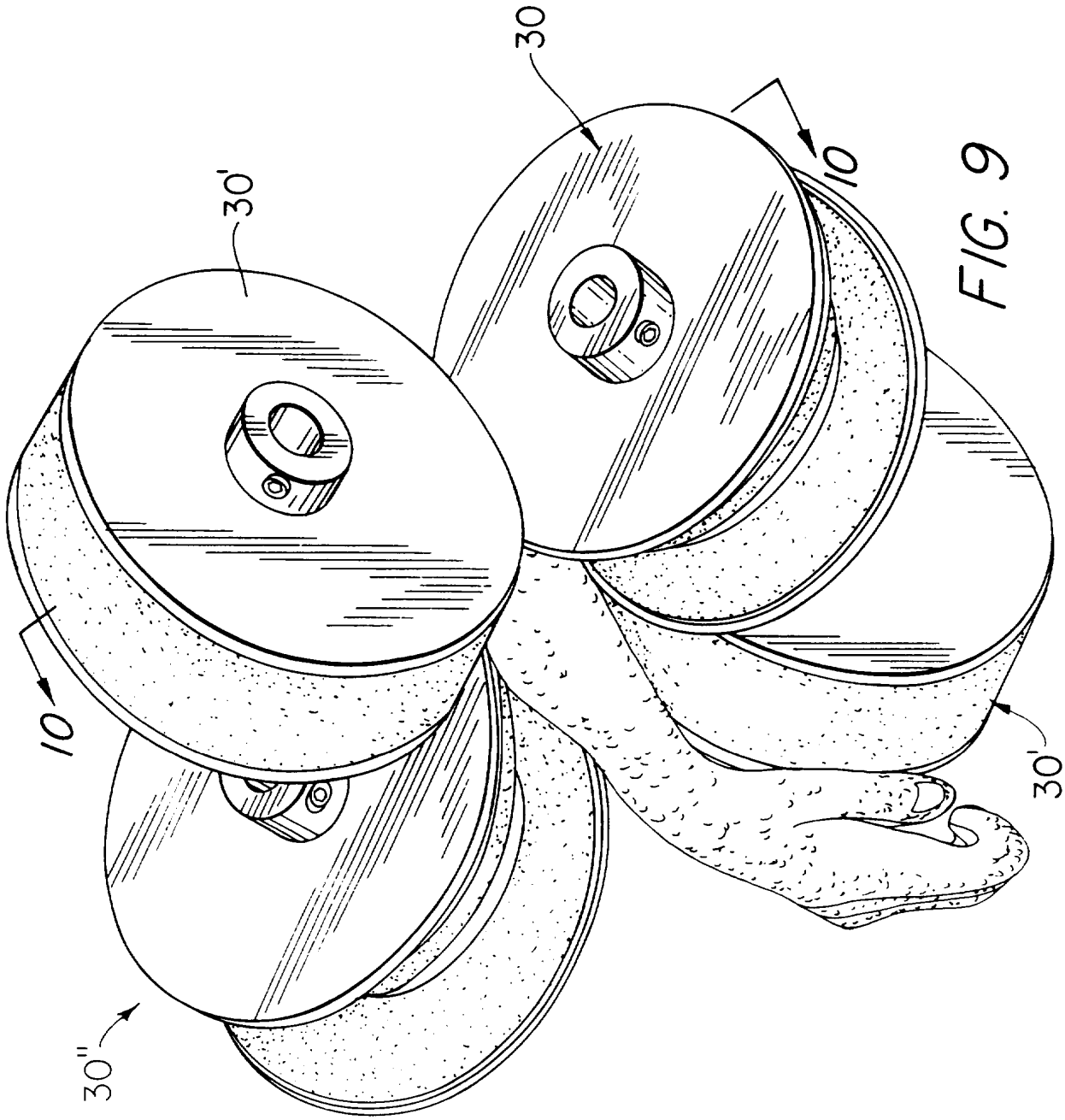

FIG. 9

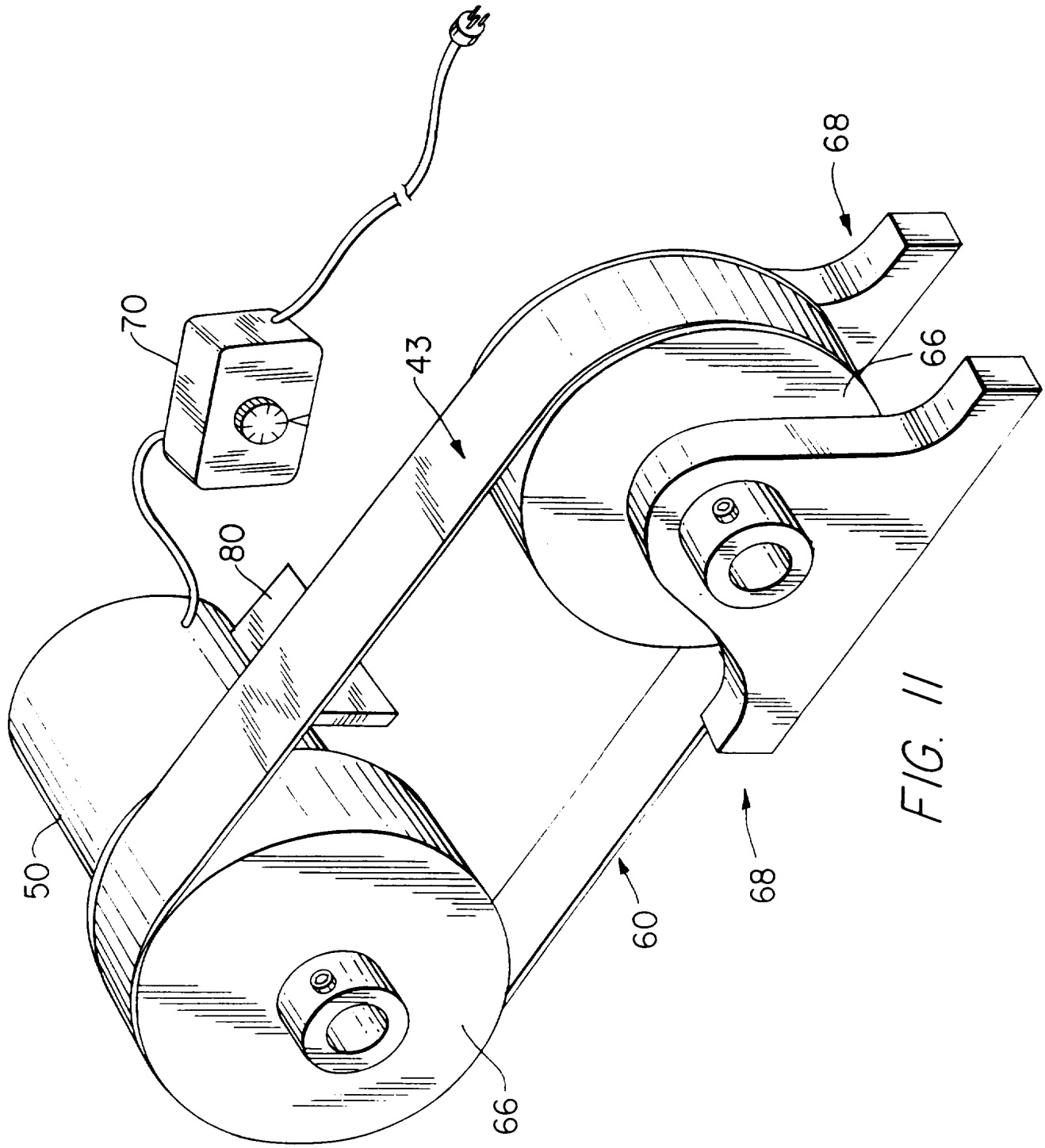

FIG. 11

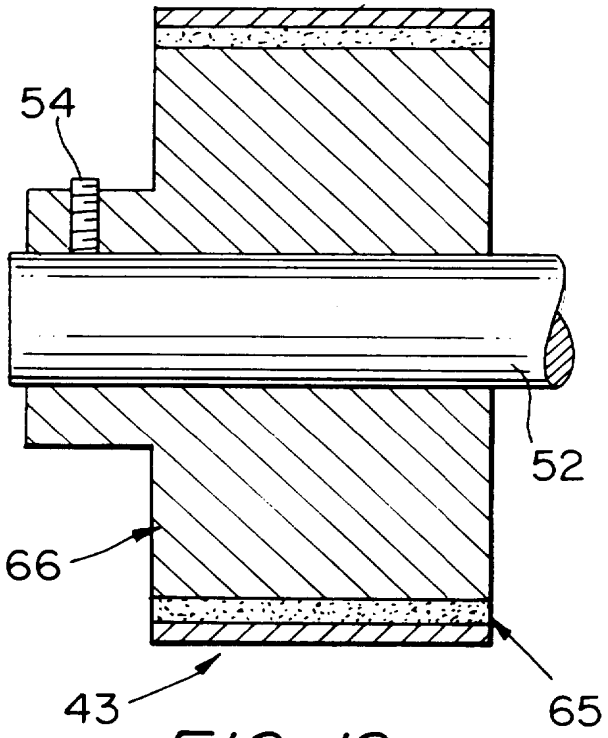

FIG. 12

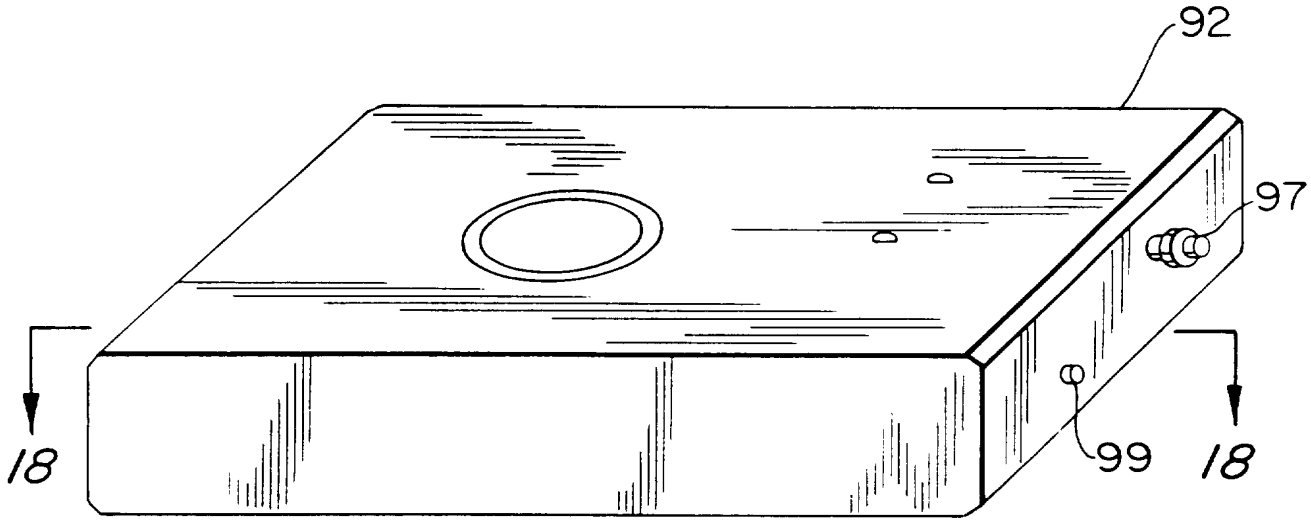

FIG. 17

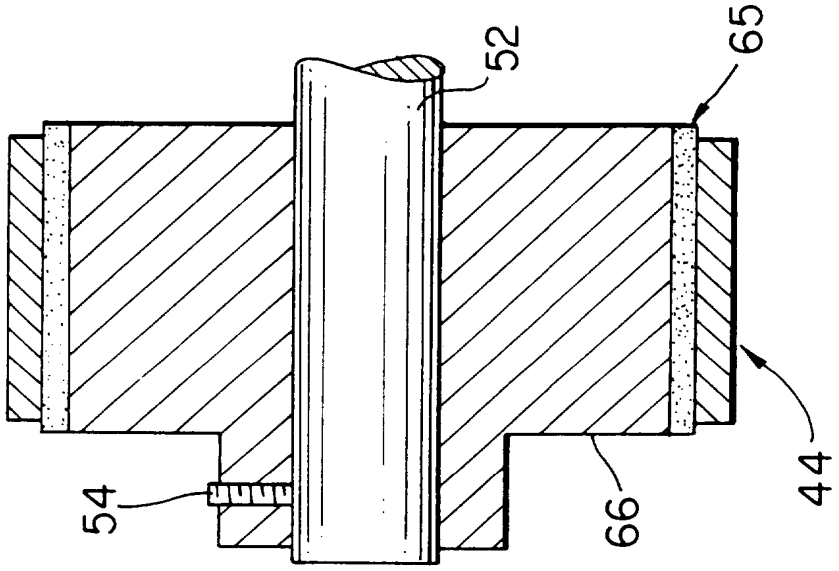

FIG. 14

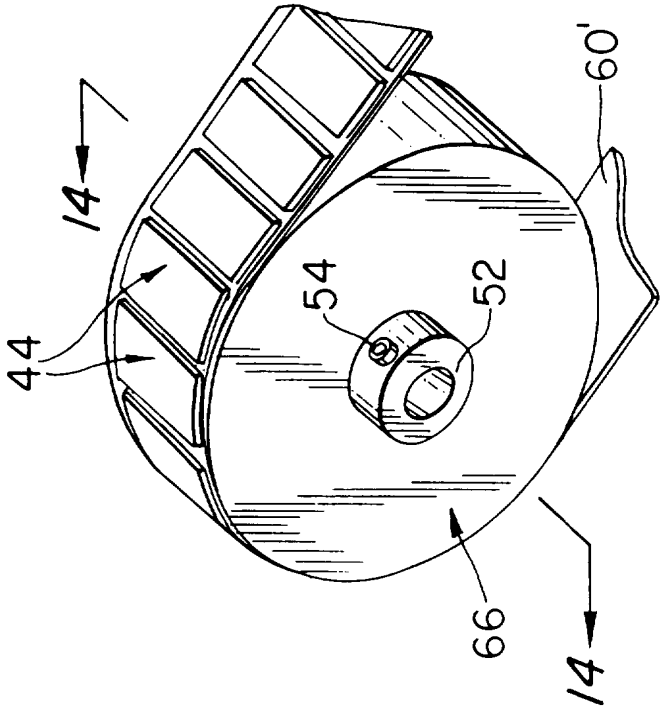

FIG 13

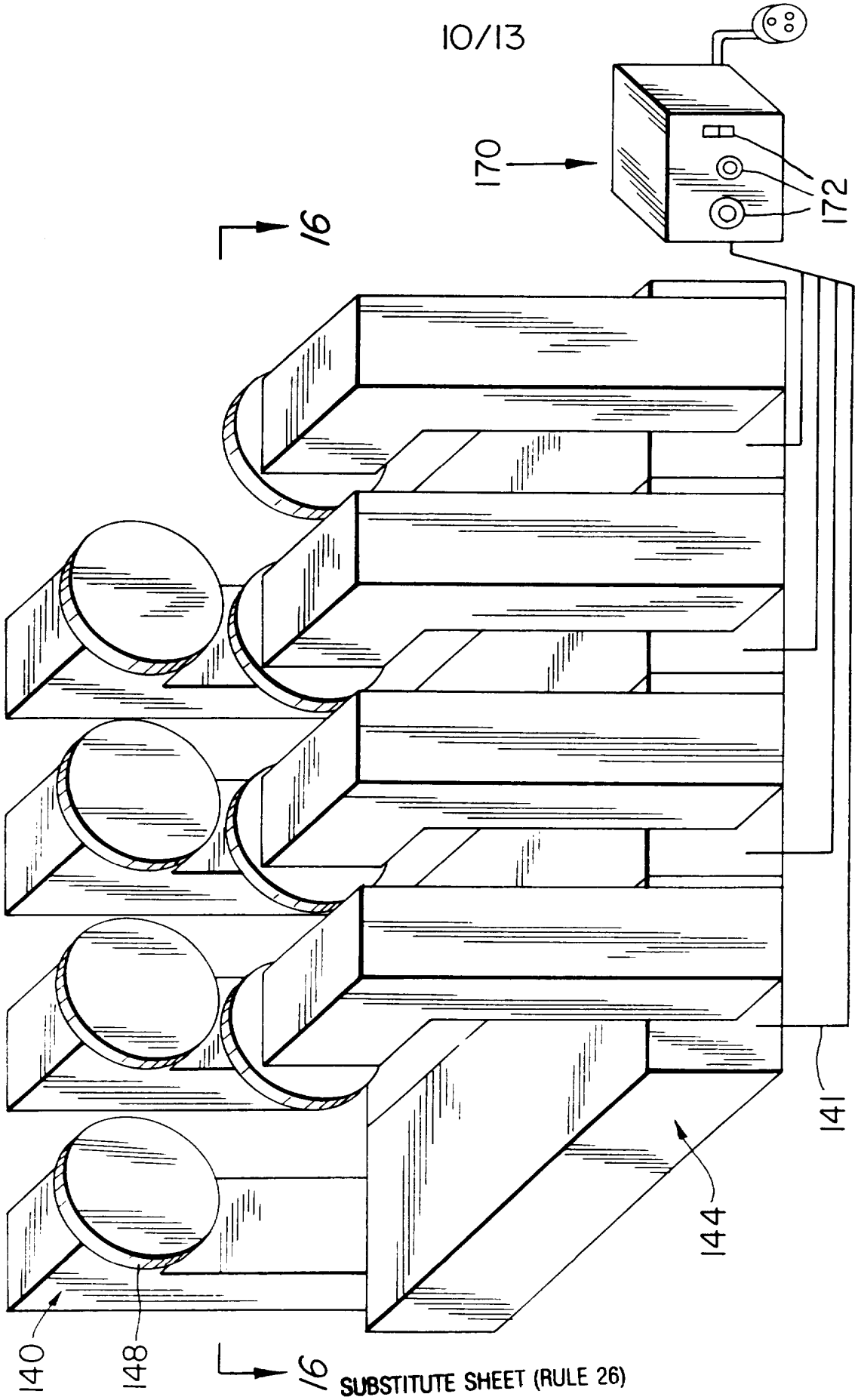

FIG. 15

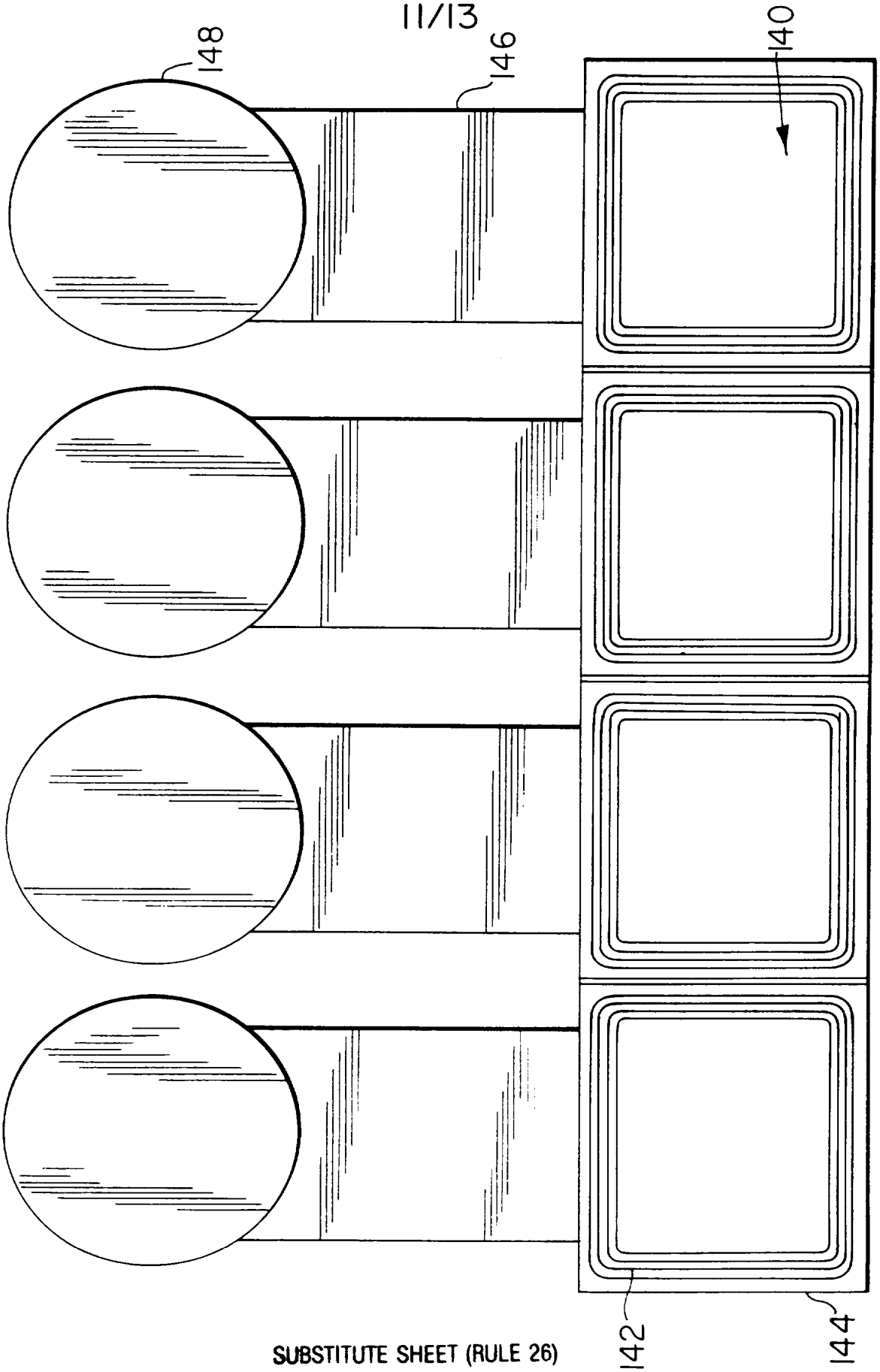

FIG. 16

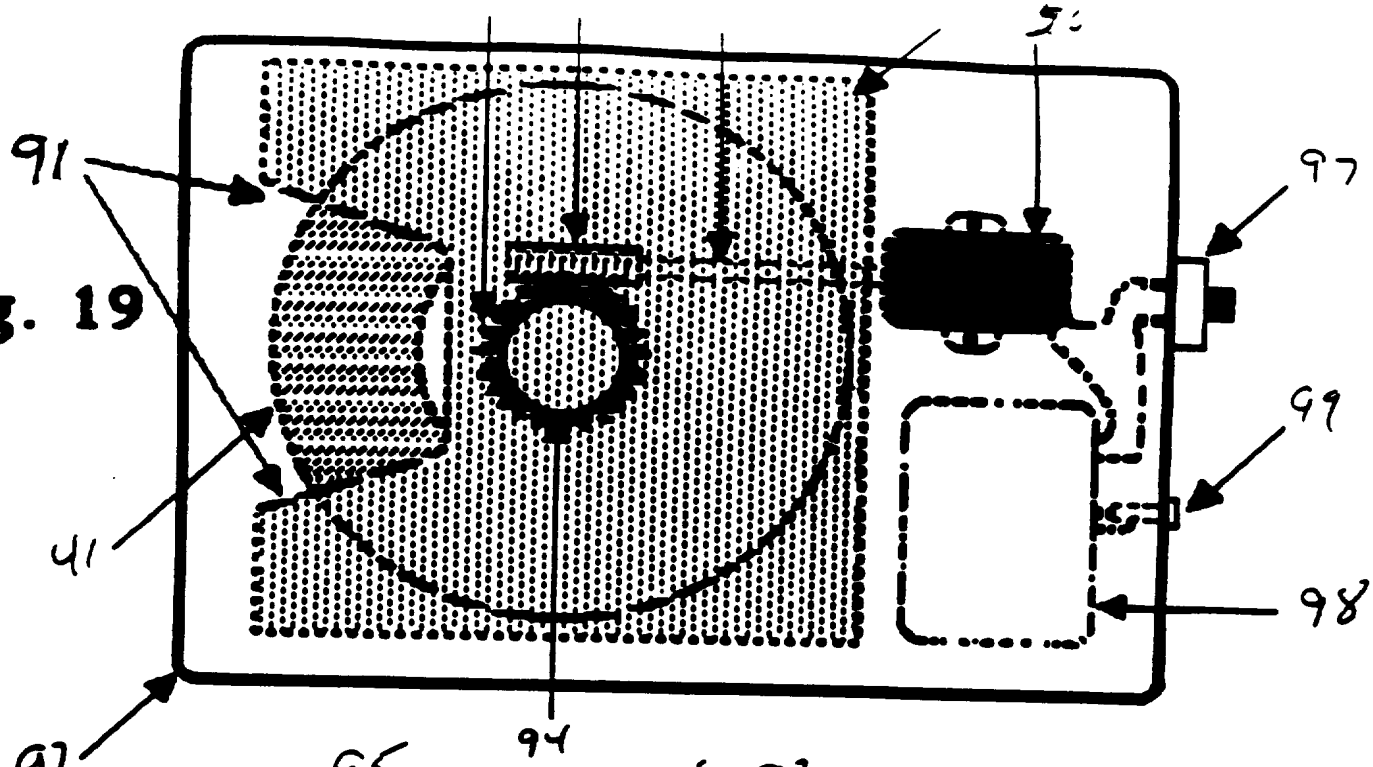

Fig. 19

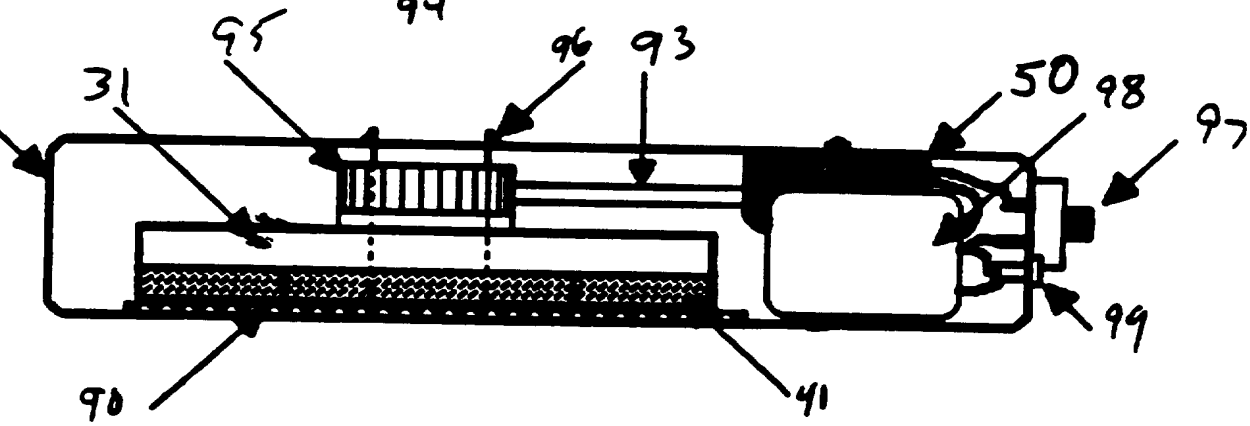

Fig.18

Fig. 20

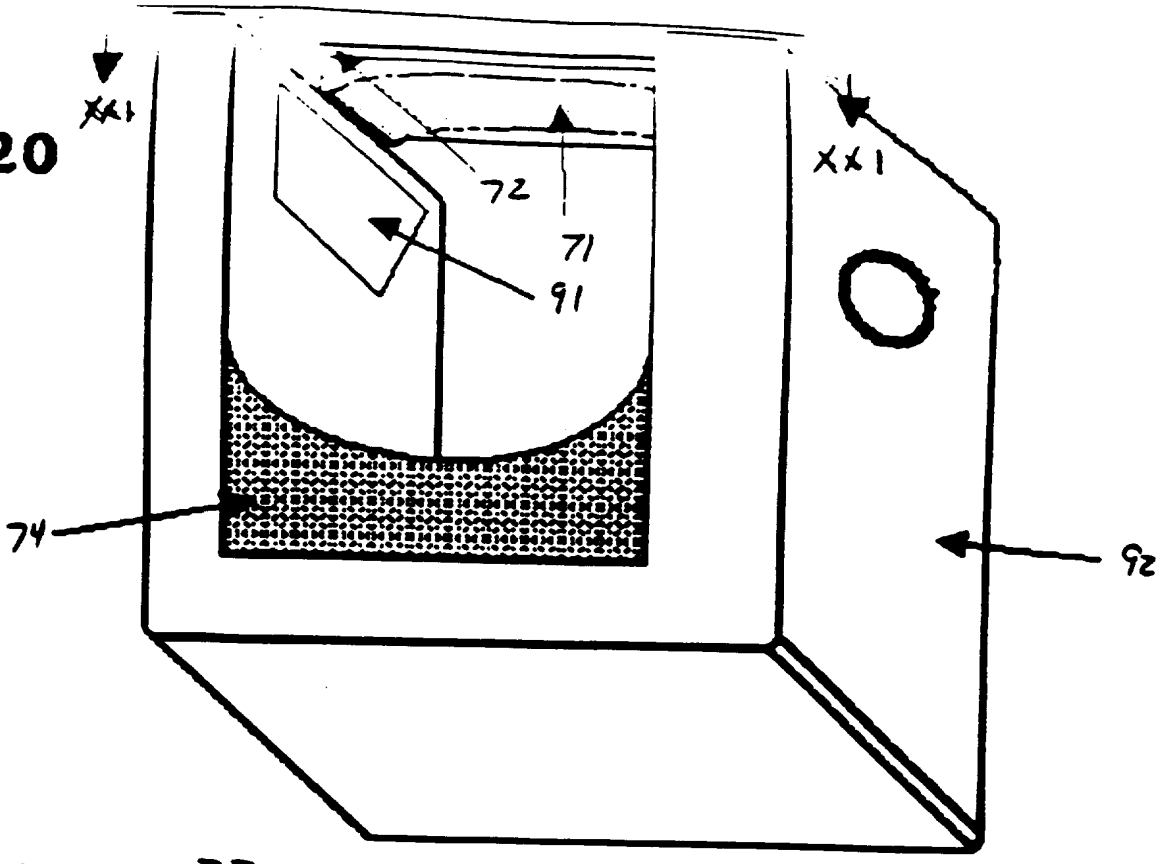

Fig. 21